A master-slave hydraulic control system is disclosed which provides an improved synchronization control together with the ability to rapidly change the stroking characteristics of the cylinders by removing and inserting a second control member into a mounting apparatus moved with the master control piston. Further, the two pistons are continuously maintained in close synchronization and are not allowed to get out of synchronization by the accumulation of more than a slight quantity of captive hydraulic fluid or oil.

7 Claims, 5 Drawing Figures
BACKGROUND OF THE INVENTION

This invention relates to hydraulic master-slave cylinder control systems and, more specifically, to the ability to maintain the master and slave cylinders of a continuously reciprocating system in synchronization.

Master-slave reciprocating hydraulic systems have been well known in the art for many years. Many attempts have been made to adequately control these systems in such a way that the systems are not damaged when certain conditions occur. One very common condition in a master-slave system in which there is a captive oil supply, is encountered when the captive oil increases in volume due to leakage past the piston on the high pressure side. When pressurized oil is pumped into a cylinder to drive the piston through its travel, a pressure differential is created across that piston. Small quantities of the high pressure oil will seek to bypass the piston and the cylinder walls and joint that oil referred to as captive oil on the relatively low pressure side of the driving piston. The captive oil is used to transmit the driving force from the driving piston to the driven piston. In order for the driven piston to properly translate its position, the portion of the system on the opposite side of the driven piston from the captive oil is generally vented or valved into a reservoir or other low pressure holding means. Inasmuch as only a relatively low pressure resists the translation of the driven cylinder and the captive oil supply is at a relatively low pressure, the pressure differential across the driven piston is generally considerably less than the pressure differential across the driving piston. Therefore, it is readily apparent that the captive oil supply will continue to increase, and when the captive oil supply increases sufficiently, this causes the two pistons to become unsynchronized and additionally creates a situation after a sufficient length of time where the piston's stroke, in addition to being unsynchronized, also is relatively uncontrollable because the travel of the driven piston has been translated with respect to the travel of the driving piston and eventually will result in the driven piston reaching its physical end of travel and being unable to further respond to the pressure transmitted to it through the captive oil supply. This can result in several problems, the most obvious one is that the tool or working mechanism attached to the driven piston is prevented from travelling through its normal required movement. A second more destructive result will be either a rupture at a weak point in the system between the two pistons or the forcing of the captive oil past the pistons in such a way that it may damage either the cylinder walls or the pistons or seals associated therewith.

To overcome this problem, there have been attempts in the past to bleed off excessive captive oil either by hand or in response to excessive pressures in the captive oil supply. Generally, the hand bleeding is accomplished by the opening of a valve which is connected to the captive oil line and thereby passing a quantity of the oil into a receptacle or reservoir. This process is fully acceptable where the requirement for such adjustment is very intermittent and is not critical to the continuing satisfactory operation of the overall working system. However, this system is not generally satisfactory where the requirement to resynchronize the movement of the cylinders is frequent and exacting or where the stroke of the cylinders is varied periodically, as the hand venting is a cut and try technique.

Alternate systems have been used where there is a pressure relief valve connected into the captive oil line and thus relieves the excessive oil when one of the two pistons reaches its physical end of travel and the other piston is still displaced from its end of travel. This creates a drastic increase in pressure and pops the pressure release valve to bleed off the excessive captive oil. This system is not totally satisfactory as it is pressure sensitive and is dependent upon the synchronization of the two pistons being so far out of synchronization that an excessive pressure is developed during normal operation, and may result in damage to the equipment. Other more automated techniques have been attempted and, among others, they include the technique of attaching to one or the other of the piston rods, an electrical contact which in turn engages a second portion of an electrical circuit, primarily a limit switch which then in turn controls an electronic or electrical valve thus opening the captive oil supply to the reservoir at anytime that the driven piston reaches its end of travel. This technique is reasonably well suited to situations where the driven piston always reaches the end of travel at a fixed point, but is highly unsatisfactory where the length of the strokes of the system are varied depending upon the work application it is accomplishing.

To utilize this system in a varying stroke environment, the end-of-travel sensor must be constantly adjusted to accomplish the bleed off. Further, this system has the drawback that on every stroke that the piston reaches its end of travel, the captive oil supply is valved to the reservoir and, in so doing, presents an opportunity for the system to excessively bleed off captive oil and thus prevent the driven piston from operating properly on the next and succeeding strokes, until such time as the captive oil supply is reestablished at its required volume or in excess of its required volume.

OBJECTS OF THE INVENTION

It is therefore an object of this invention to improve automatic synchronization control for a master-slave hydraulic system.

It is another object of this invention to selectively control the piston strokes of a master-slave hydraulic system while maintaining synchronization.

It is still another object of this invention to selectively control a hydraulically coupled master-slave stroking system safely in an explosive and hostile environment.

It is further an object of this invention to eliminate the need to interrupt the operation of the hydraulic system for long periods of time to change piston stroke lengths.

It is an additional object of this invention to control synchronization of the pistons of a master-slave hydraulic system independent of stroke length.

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention as illustrated in the accompanying drawings.

SUMMARY OF THE INVENTION

The foregoing disadvantages of the prior art are overcome and the above objects accomplished by the electrical sensing of the position of one piston with respect to the position of the other piston of the two cylinders.
and the gradual readjustment of the captive oil supply in accordance with their displacement from each other at prescribed points in their travels. Additionally, the system is capable of rapid change in the length of the strokes of the pistons by the removal and reinsertion of selective control members which act to control the stroke of the master and slave pistons. An additional advantage of this system is accomplished by the use of magnetic sensing proximity switches to detect positions of travel, and thus avoid exposed electrical switches which can be exceedingly hazardous in explosive and unstable environments.

These advantages are accomplished by connecting proximity sensors into a control circuit which gradually bleeds off excessive captive oil in response to the sensing of the piston positions. When the piston positions are displaced by a large amount of travel and thus a large amount of time between their datum positions, the bleed off valve is controlled proportionally and thus bleeds off a larger quantity of oil. This process is accomplished at a rate which gradually resynchronizes and then maintains the pistons in synchronization. The interchangeability of the control member does not affect the resynchronization circuit or sensing apparatus inasmuch as the sensing data points for resynchronization are designated as the midpoint of travel for the piston, and thus the pistons need not be forced to their end of travel in order to activate the resynchronization controls.

FIG. 1 is a line schematic diagram of the hydraulic equipment controls and hydraulic connections of the invention.

FIG. 2 is a schematic electrical diagram of the related control elements and circuitry.

FIG. 3 is a schematic of the electrically controlled directional valve.

FIG. 4 is a perspective view of the interchangeable control member together with the midpoint detector and related limit controls.

FIG. 5 is a perspective view of an electrical control element embodied in the interchangeable control member of FIG. 4, together with an illustration of the attaching of one limit dog to the interchangeable control member.

DETAILED DESCRIPTION

Inasmuch as the invention may be utilized in many different environments and may be adapted for many separate and diverse uses, the description of the invention will be made referencing the schematic diagrams as they are fully adequate for a complete understanding of the invention. Some of the description will be made referring to an electrostatic printing environment, only by way of example.

The terms, master cylinder and slave cylinder and piston, as used in this application and claims are used to mean a cylinder or piston which controls another cylinder or piston and a controlled working cylinder or piston, regardless of which cylinder or piston is actually powered by pressurized hydraulic fluid from an external source. Additionally, the term magnetic as applied to the limit dogs or limits and describing material includes all materials ferrous and nonferrous which are attractable to a magnet.

Referring to FIG. 1, the primary control of the system is influenced through the movement of the piston in master cylinder 10. Master cylinder 10 is fixed and provided with the necessary motive power to move its piston 11 by pressure source 16. Pressure source 16 is illustrated as a hydraulic pressure pump, however, it may be any convenient pressure source and could even be hydrostatic or pneumatic pressure.

Connected to the captive oil side of piston 11 and cylinder 10 is captive oil line 22. Captive oil line 22 provides a pressure route to the captive oil side of slave cylinder 12 and piston 13. Piston 13 is connected by way of a piston rod to the working tool 14.

In the explanation of operation, working tool 14 will be characterized as a drive motor and electrostatic painting disc, but may be any suitable tool for the job being performed.

Opposite the captive oil side of piston 13 is a portion of cylinder 12 which may be either valved to the reservoir 20 or may be pressurized by the selective positioning of directional control valve 18. To provide the connection between cylinder 12 and the directional control valve 18, the slave pressure line 17 is provided. The slave pressure line 17 does not always have a positive pressure exerted upon it but may be periodically vented or valved. Directional control valve 18 is either a unitary valve or a system of individual valves electrically controlled to accomplish the same purpose. The unitary valve could be such as one illustrated in FIG. 3 where the solenoids 74, 76 rotate the core 72 of valve 18. Two paths 73 formed in core 72 provide continuity between the pressure line 19 and one of the cylinders, either the master 10 or slave 12, and at the same time provide continuity between the other of the cylinders and the drain line. Thus, whenever pressure is applied from the pressure source 16 to one of the cylinders 10, 12, the other cylinder is relieved and allowed to drain back through directional valve 18 into the reservoir 20.

As one can see from the diagram of FIG. 1, the oil trapped between piston 13 and piston 11 is, in theory, constant in volume. However, due to wear of the periphery of pistons 11 and 13 and the wear on the internal cylinder walls of cylinders 10 and 12, high pressure hydraulic fluid from pressure source 16 forced into either cylinder 10 or cylinder 12 may be forced past the seals on pistons 11 and 13. As this occurs, the volume of the captive oil in line 22 and the two cylinders 10 and 12 will increase. Other causes of increase in the captive oil supply can be an increase in temperature as the system is operated.

In order to relieve the increased volume of the captive oil supply, a relief line 25 or bleed return line 25 is connected to the captive oil line 22, and includes bleed valve 24. The bleed return line 25 terminates with the reservoir 20. The volume of the captive oil in the cylinders 10, 12 and captive oil line 22 may be reduced at anytime by the opening of a bleed valve 24 inserted into bleed return line 25. By controlling the amount of opening and the length of time of opening of valve 24, the reduction of the captive oil supply may be very finely controlled. In accurately controlling the captive oil volume, the relative positions of pistons 11 and 13 are finely controlled, and thus the operation of piston 11 within hydraulic cylinder 10 may be precisely translated into the appropriate positioning of piston 13 within cylinder 12.

When a working tool, such as a drive motor for an electrostatic painting disc, is mounted on the shaft which is connected in turn to the rod of piston 13, the
precise positioning of the drive motor 14 may be accurately controlled. 
In an environment which is hostile to finely machined hydraulic cylinder and shaft surfaces, it may be necessary to provide a protective shroud on the working cylinder to eliminate contamination and protect the equipment. Such a shroud 34 is mounted around the slave piston shaft connected to slave piston 13 and extending generally downward from the working tool 14 and enclosing at least a portion of the slave cylinder 12. This shroud will reciprocate together with the movement of piston 13.

To accurately sense the position of piston 11 within cylinder 10, a connecting rod or piston shaft is extended through the end portion of cylinder 10 and mounted thereon are extensions for holding control members.

A control member 42, which is interchangeable, is removably attached to the mounting bracket 43 and shaft extending from piston 11. This control member 42 may be in many forms but is preferably in the form of a light weight, rigid, nonmetallic material in the form of either a generally U-shaped channel or other convenient structural shape. This control member is suitable for removal and replacement with ease by releasing holding means or clip 45. Likewise, attached to the output shaft of piston 11 is a member of a magnetic or ferrous material 28 which is hereafter referred to as the master dog 28. Positioned rigidly at a point which is the midpoint of travel of one end of the master dog 28 is a magnetic proximity sensing switch 26. This switch 26 reacts when the magnetic material in master dog 28 comes into close proximity thereto.

Interchangeable control member 42 has positioned, at preselected locations thereon, two relatively small clamping pieces of magnetic material 38, 40. These two pieces may either be adjustably mounted or rigidly and fixedly mounted as desired. In FIG. 1, these two magnetic pieces are designated as 38 for the up limit dog and 40 for the down limit dog. Mounted in a preselected fixed position in proximity to the paths of dogs 38, 40 is a magnetic activated sensing switch 36 of the double pole, double throw type. As one dog comes in proximity to the magnetic activated sensing switch 36, the switch is tripped in response to that dog and changes its state from a connection in one circuit to a connection in a second circuit and the process is reversed when the second dog approaches the sensing switch 36 from the opposite direction.

This will be further expanded upon in the operation section of this specification.

Attached to shroud 34, or any other convenient mounting support which moves in response to the movement of piston 13, is a bar or dog 32 of magnetic material. At a point which represents one end of the dog when piston 13 is at its midpoint of travel, magnetic actuated proximity sensing switch 30 is fixedly mounted. This reacts to the presence of dog 32 from the time that piston 13 is at its midpoint of travel in either particular direction. Illustrated in FIG. 1, the switch is activated by dog 32 when piston 13 is moving downward and reaches its midpoint of travel in the downward direction.

Referring to FIG. 2, the schematic control diagram for the appropriate switches and controls, power is provided by power source 44. Connected in series with power source 44 is a double pole, double throw magnetic actuated proximity switch 36 which responds to one of two actuators 38, 40. The ferrous actuated switches in the preferred embodiment have internal magnets which cause a change in switch positions in response to the proximity of the ferrous or magnetic material of the up and down limit dogs 38 and 40. Branching from the terminals of the switch 36 and connected one side in parallel with each other is an up solenoid 74 and a down solenoid 76. Continuing through the circuit, the up and down solenoids 74 and 76 are in turn connected back to the power source 44.

Branching from the down solenoid loop prior to down solenoid 76 and after double pole, double throw switch 36 is a parallel circuit extending to the power source 44. In this parallel circuit and connected in series is proximity sensing switch 30 in turn connected to proximity sensing switch 26, which in turn is connected to solenoid bleed valve 24.

Proximity sensing switch 30, associated with the slave piston 13, is normally maintained in its open position when the magnetic dog 32 is not in proximity to sensing switch 30.

Magnetic actuated sensing switch 26 is normally maintained in a closed position during the time when the magnetic bar or dog 28 is not in proximity to switch 26. Solenoid valve 24 is selected from the type which normally operates to open the valve only when there is a current flowing through the solenoid portion of the control mechanism.

As it is desirable to be able to rapidly vary the length of stroke of piston 12 in order to efficiently change the painting coverage of the electrostatic painting system, control member 42 is provided in an interchangeable characteristic. As illustrated in FIG. 4, the interchangeable control member 42 is supported on one end and is shaped in a generally U-shaped channel. This provides a member which moves in synchronization with the piston 11 of master cylinder 10. Mounted within the U of this interchangeable member are two adjustable blocks or pieces of magnetic material 38, 40. The amount of movement of the piston 11 and thus the other related portions of the system is determined by the positioning of these blocks on control member 42, in response to switch 36 which controls directional control valve 18, as described earlier. For rapid change in the stroke characteristics of the system, it is merely necessary to remove one interchangeable control member and insert another with differently located blocks 38, 40.

The control member may be fitted with an electrical element 46 which, when properly positioned, alters a related electrical circuit. Examples would be a resistive or capacitive element for controlling the speed of the working motor 14 if speed changes are necessitated by the change of stroke length. Other changes could be a reduction or increase in the pump speed to control paint flow. Other variables controllable by the above techniques would depend upon the system usage.

A better understanding of the operation of the invention may be had from the following description of the mode of operation.

OPERATION

To more clearly illustrate the operation of this master-slave control system, the operation will be described in the environment of an electrostatic painting booth where the slave cylinder 12 moves a drive motor
and electrostatic painting disc 14 in a vertical movement to evenly distribute charged paint droplets onto articles passing through the painting booth. Hydraulic pump 16 or pressure source 16 is powered to continuously operate and thus provides pressure through the hydraulic fluid through lines 19 to control valve 18. During an upstroke of the slave piston 13, the hydraulic pressure is diverted from line 19 through pressure line 17 to the pressure face of piston 13 of slave cylinder 12. At the same time that control valve 18 is diverting the pressurized hydraulic flow from pump 16 to line 17, it is also providing a relief passage from line 23 through valve 18 to return line 21. Return line 21 then terminates and dumps its return oil into reservoir 20. As piston 13 is forced up by the pressurized fluid in line 17, the capacity of cylinder 12 on the captive oil side of piston 13 is reduced and the hydraulic fluid or oil trapped in that portion of the cylinder is expressed through line 22 into the captive oil side of master piston 11 in cylinder 10. Since the dynamics of the system and the pressures developed in the different lines vary, the pressure in line 17 and the working side of cylinder 12 of necessity exceeds that on the captive side of piston 13 in cylinder 12 and in line 22. As there is a pressure differential between the two bodies of oil, there will be some small amount of leakage of the high pressure oil past piston 13 into the accumulated captive oil.

As piston 13 and thus tool 14 are moved upward, the captive oil is forced through line 22 and forces piston 11 down. As tool 14 moves upward, shroud 34 moves upward and moves the long dog 32 past proximity sensing switch 30. When piston 13 reaches its midpoint of upward travel, the magnetic dog moves out of proximity with sensing switch 30.

Since piston 11 and piston 13 desirably move in synchronization, the point at which piston 13 reaches its midpoint should be the same point in time as when piston 11 reaches its midpoint of travel. Thus, magnetic member 28 will no longer be in proximity to sensing switch 26 after piston 11 passes its midpoint in a downward stroke in response to the upward movement of piston 13. The conditions described above with piston 13 moving up and piston 11 moving down will continue until such time as magnetic dog 38 comes in proximity to double-pole, double-throw proximity switch 36. At this point, the magnetic dog 38, approaching from the top of switch 36 will shift the state of switch 36 so that the down solenoid 76 activates directional valve 18. When the down solenoid 76 activates directional valve 18 to change the direction of movement of the pistons 11 and 13, the pressure from pump 16 is delivered through lines 19 and 23 to the high pressure side of piston 11. Piston 11 is forced upward by this high pressure hydraulic fluid and it moves with it the long magnetic dog 28 and the interchangeable control member 42, together with the magnetic limit dogs 38, 40 mounted on the magnetic control member 42. The accumulated captive oil in line 22 and the captive oil portions of cylinders 10 and 12 forces the slave piston 13 downward and also lowers the paint disc driving motor 14, shroud 34, and long magnetic dog 32.

As illustrated in FIG. 1, long magnetic dog 32 has progressed downward to the point where it has caused proximity sensing switch 30 to sense its presence and close switch 30. The long magnetic dog 32 has continued to progress until it has begun to overlap proximity switch 30, and at the point in time illustrated in FIG. 1, long magnetic dog 28 has just approached into activating proximity to sensing switch 26. In the condition illustrated in FIG. 1, with switch 30 closed and sensing switch 26 about to be opened, the solenoid valve 24 was initially energized when switch 30 closed and will remain open until magnetic dog 28 opens switch 26. Since line 25, connected between captive oil line 22 and the reservoir 20, is fairly small diameter line and only bleeds off a small quantity of oil as piston 11 continues to move upward, piston 13 will continue its downward movement not withstanding the fact that valve 24 has been opened. Valve 24 thus bleeds off a portion of the captive oil supply. This condition is necessitated by the fact that high pressure oil is being forced past pistons 11 and 13 during their respective pressure strokes, and thus the captive oil supply in the captive oil portions of cylinders 10 and 12, together with captive oil line 22, continually increases. In this accumulative arrangement, the slave piston 13 will always tend to lead the master piston 11, and thus the bleeding can be controlled by valve 24 only on the downstroke of piston 13.

As one can readily see, if, for some reason, the piston 13 lags piston 11, the movement of piston 11 in controlling magnetic dog 28 will cause switch 26 to open prior to the closing of switch 30 by the proximity of magnetic dog 32, and thus the solenoid valve 24 will not be opened to drain off any of the captive oil. As piston 11 continues its upward movement under the influence of the pressurized oil coming from line 23, proximity switch 36 begins to come under the influence of the stroke reversal magnetic limit dog 40. When stroke reversal magnetic limit dog 40 is sufficiently close to proximity switch 36, the switch is changed in its state to the second position of the double-pole, double-throw switch, and this, in turn, activates the upper solenoid which will then condition directional valve 18 to route the oil which is received under pressure from line 19 through line 17 to slave cylinder 12 for a repeat of the above-illustrated cycle.

It is many times desirable to quickly change stroke lengths when there are many short runs of parts through a painting booth. The dimensions of the parts will vary, depending upon the type of part being painted at any particular time. As most of the small parts are grouped together and most of the large parts are grouped together, and in many cases, a run will be made with identical parts, it is desirable to control the stroke of piston 13 so that the painting disc and drive motor 14 are only stroked over the minimum necessary distance for the most efficient painting. For a series of parts with a very small vertical dimension, the dogs 38 and 40 mounted on interchangeable control member 42 can be moved toward each other. The movement of these dogs normally requires that the system be shut down and the production of the system curtailed while the adjustment is made. It is therefore advantageous to provide additional interchangeable members 42 with preset dogs. When it is desirable to change from one stroke length to another, member 42 may be removed and a substitute member may be reinserted into the control bracket, thus changing the stroking characteristics of the entire system. Interchangeable control members may be prepared for use with specific types of operations and so marked for fast efficient changes by unskilled operators.
It may be additionally necessary, due to the change in the length of stroke and thus the increased coverage of the painting mechanism over a very short stroke, to reduce the speed of the disc drive motor 14 or the speed of the stroking piston 13. This may be accomplished through a resistive or capacitive network which may be permanently attached within the interchangeable control member and thus plug into a circuit when the control member is inserted in the control bracket. Thus, the necessary stroke change can be made at the same time that the necessary speed change may be made. Alternatively, the control member with the capacitive or resistive elements embodied therein may control the paint pump speed or any other electrically controllable variable which is necessary to accomplish the desired work result. Additional magnetic dogs can be added (fixed) to the side of control member 42 to act on other switches, thereby controlling still other functions.

While the above control system has been described and illustrated in the electrostatic painting environment, this should not, in any way, be considered as limiting to that environment as this mechanism may easily be used in any other environment requiring a hydraulic master-slave cylinder mechanism and requiring accurate automatic reversal of movement at predetermined points in the piston travel. It is particularly advantageous where it is necessary to periodically change the lengths of the piston strokes to accommodate varying conditions.

Precise control and automatic correction of nonsynchronous drifting of the slave piston stroke, with respect to the master piston stroke, is a prerequisite for the programmed operation of any hydraulic master-slave drive system, whether program introduction is by insertable members, as described, or by other insertable instructions which bear upon the master stroke functioning and, in turn, by hydraulic coupling bear upon the slave stroke functions.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A master-slave hydraulic, reversible system comprising:
   a slave cylinder having a piston;
   a master cylinder having a piston;
   a pressure line connecting said cylinders to form a captive volume of a pressure medium; and a pressure source for furnishing working pressure alternately to said cylinders; the improvement comprising:
   a first position sensing means for sensing the position of said slave cylinder piston and providing an output;
   a second position sensing means for sensing the position of said master cylinder piston and providing an output;
   and a captive volume pressure medium relief means responsive controlled by the outputs of said sensing means to automatically synchronize the movements of said pistons during the operation of said system.

2. The system of claim 1 wherein said first sensing means completes an electrical connection to operate said relief means, whereby excessive captive oil is removed from said captive oil volume.

3. The system of claim 2 wherein said second sensing means breaks an electrical connection to prevent further operation of said relief means to prevent additional captive oil from being removed thereby limiting the time that captive oil may be removed from said captive oil volume to the time between the functioning of said first sensing means and the functioning of said second sensing means.

4. The system of claim 1 wherein said first and second sensing means are positioned to detect the midpoint of travel of said pistons.

5. The system of claim 1 wherein said improvement further comprises:
   stroke length control means;
   said stroke length control means further comprising a sensing means;
   and limit defining means movably positioned to intermittently activate and deactivate said sensing means in response to the movement of the piston of one of said cylinders, said sensing means operatively connected to a means for reversing the stroke of said pistons within said cylinders.

6. The system of claim 5 wherein said limit defining means further comprises a preselected electrical component for altering the operating characteristics of related and associated electrical circuits.

7. The system of claim 5 wherein said limit defining means is adapted to be removable for easy substitution.